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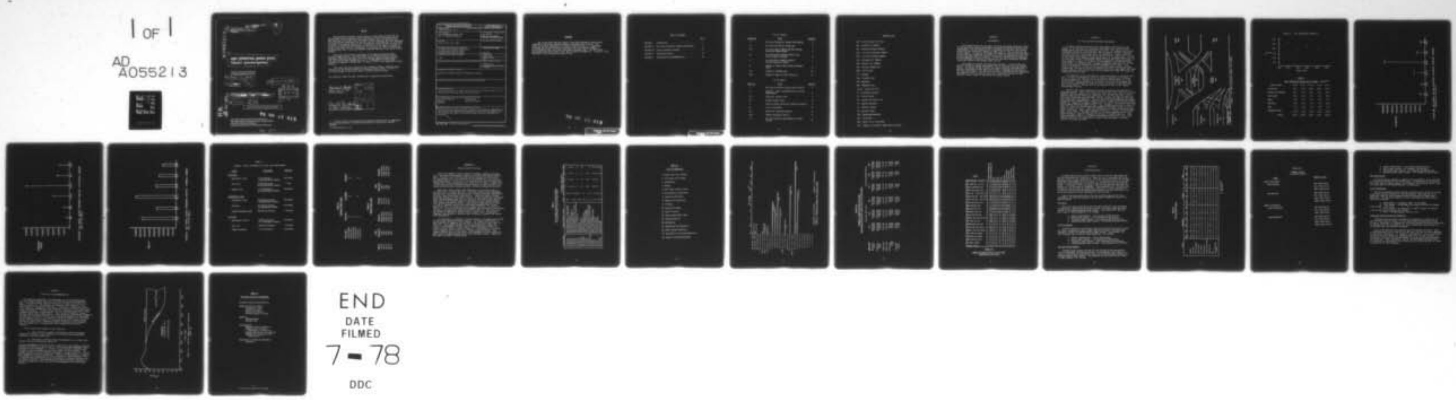

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AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

David C. Hall

David C. Hall, Lt, USAF
Project Engineer

Robert R Barthelemy

Dr. Robert R. Barthelemy
Actg Chief, Energy Conversion Branch

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Present and future Terrestrial Power (Electrical and Thermal) requirements of the Air Force are summarized and categorized at both base and subbase level, with consideration given to applicable energy conversion technology and potentials.

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FOREWORD

This is the final Technical Report on the USAF Terrestrial Energy Study conducted by the Energy Conversion Branch, Aerospace Power Division. The effort was jointly sponsored by the Power Systems Division, U. S. Department of Energy and the Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio under Interagency Agreement #1013. The work herein was accomplished under Project 3145, Task 23, Work Unit Number 12. Lt David C. Hall, AFAPL/POE, is the responsible project officer.

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ABBREVIATIONS

USAF - United States Air Force

AAC - Alaskan Air Command

ADC - Aerospace Defense Command

AFLC - Air Force Logistics Command

AFSC - Air Force Systems Command

SAC - Strategic Air Command

MAC - Material Air Command

BTU - British Thermal Unit

MBTU - Million BTU

KW - Kilowatt

KWh - Kilowatt hours

MW - Megawatts

MWh - Megawatt hours

lbs/hr - pounds per hour

AC - Alternating Current

DC - Direct Current

PSI - pounds per square inch

^{o}F - Degree Fahrenheit

CF - Chemical fueled

NF - Nuclear fueled

MHD - Magnetohydrodynamics

GAL - US gallons

BOE - Barrel of oil equivalent

CBR - Chemical, Biological, Radiological warfare

SECTION I

Introduction

This report covers over two years of work by the Energy Conversion Branch on USAF terrestrial energy requirements and potential methods of meeting those requirements. The main objective was to determine how the USAF could achieve a most efficient terrestrial energy use state, both in terms of resources and mission impact. In order to fully meet this objective, the governing parameters of the study were formulated, considering not only the technology options, but also the practical areas of logistics, utilization, maintenance and management. We have attempted to find and include the best available information and techniques that relate to USAF energy supply and use.

This report is divided into three major sections. The first describes the USAF terrestrial energy requirements, both at the base level and sub-base levels. The second section indicates the energy conversion technology that is generally applicable to USAF needs and includes a comprehensive data base on all these technologies. The third section gives a breakdown of the technologies most generally useful to the Air Force and a preliminary estimate of their potential, both in terms of application and energy savings.

SECTION II

Air Force Terrestrial Energy Requirements

To obtain present terrestrial energy requirements, both electrical and thermal, it was necessary to contact Air Force energy users from the Major Command down to the individual equipment user levels. Our manpower and funding limitations necessarily restricted this contact; however, we have included at least 90% of all Air Force energy use in our compilation. Figure 1 shows the Air Force terrestrial energy flow pattern derived from our compilation. As seen in this Figure, even though our major energy source is purchased electricity, the Air Force does require a considerable amount of nonelectric energy to maintain force readiness. Figure II and Table 1 give breakdowns of terrestrial energy usage trends. The downward trend in energy consumption shown from FY73 to FY76 is from the extensive conservation efforts throughout the Air Force. This trend is leveling out, as most of the possible conservation efforts have been accomplished. One must be careful in extrapolating future requirements from these figures, however, since mission and/or policy changes can change USAF energy use dramatically within a year.

The prediction of future terrestrial energy requirements is extremely difficult. As with any organization, there are numerous agencies which influence Air Force energy use. The one area of certainty in future energy use is that unless dramatic mission changes are instituted or new types of equipment and facilities are incorporated into the Air Force, the overall energy requirement will not be reduced. The best that can be expected is that it will remain approximately the same.

The basic data used to generate the energy flow pattern was gathered by a three-step process. First, the raw data for Fiscal Years 1975, 1976, and 1977 were assembled into two categories; Air Force base level and sub-base level. Fiscal 1975 was chosen as the first year examined as it is the first year for which complete and accurate data were available. Second, the base and sub-base level data were broken down into categories. The base level data were assembled into Maximum Average Electrical Demand (peak), monthly Electrical Energy Use and monthly Thermal Energy Use. Examples are shown in Figures III, IV, and V. The sub-base level data were assembled into three demand levels: High, Intermediate, and Low, as shown in Table II. Third, all the data were then assembled into general levels of use as shown in Tables III and IV. Table III indicates the 13 levels of electrical power used in this study. These levels encompass 90-95% of all electrical requirements within the Air Force. The other 5-10% of use is highly equipment-specific and widely scattered. Table IV indicates the 9 levels of thermal power use. These levels encompass 85-90% of all thermal requirements within the Air Force. The remaining 10-15% of the requirements are again highly equipment- or process-specific and widely scattered.

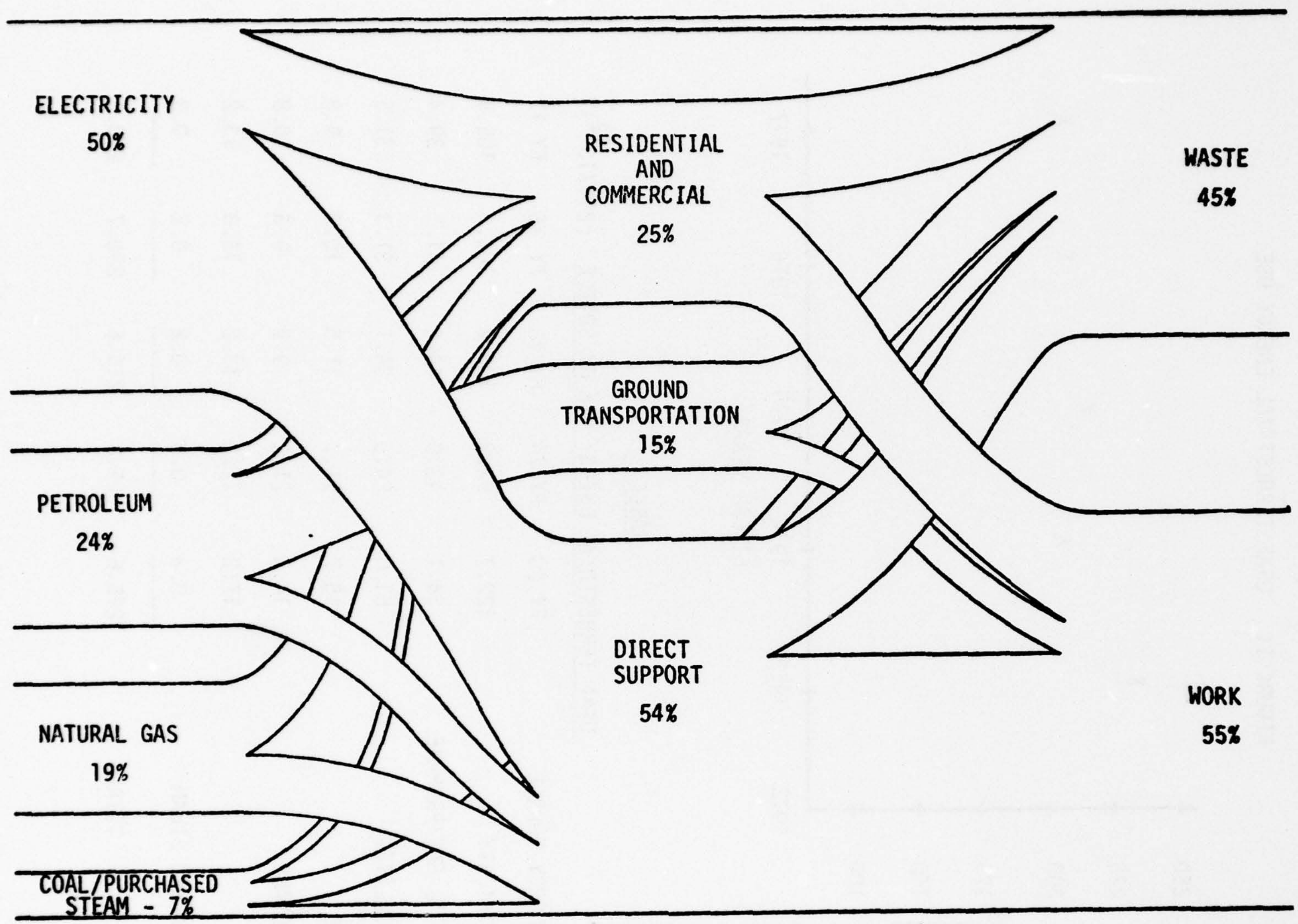


FIGURE I. AIR FORCE TERRESTRIAL ENERGY FLOW DIAGRAM

FIGURE II. USAF TERRESTRIAL ENERGY USE

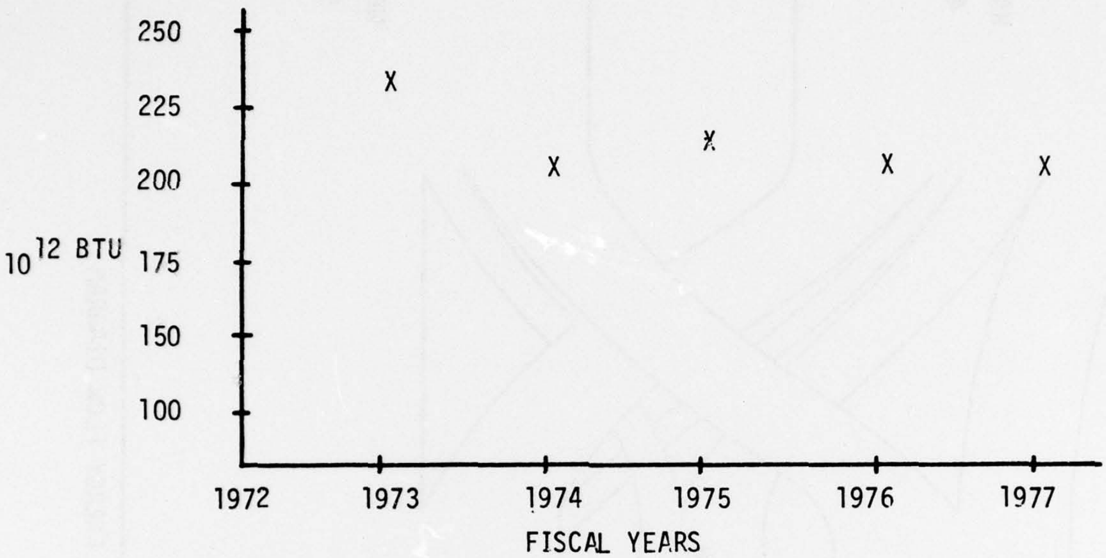


TABLE I

USAF TERRESTRIAL ENERGY USE BY SOURCE ($BTUX10^{12}$)

ENERGY SOURCE	FY 73	FY 74	FY 75	FY 76	FY 77
ELECTRICITY	122.7	92.3	103.3	104.3	105.9
NATURAL GAS/PROPANE	54.1	43.8	44.4	41.7	39.4
DISTILLATES	51.0	24.3	34.1	31.3	31.5
MOGAS	15.7	11.7	11.5	10.3	9.8
RESIDUALS	14.6	21.2	9.9	9.6	10.8
COAL	17.2	12.2	13.2	13.3	13.2
PURCHASED STEAM	0.3	0.3	0.2	0.2	0.3
TOTALS	275.6	205.8	216.6	210.7	210.9

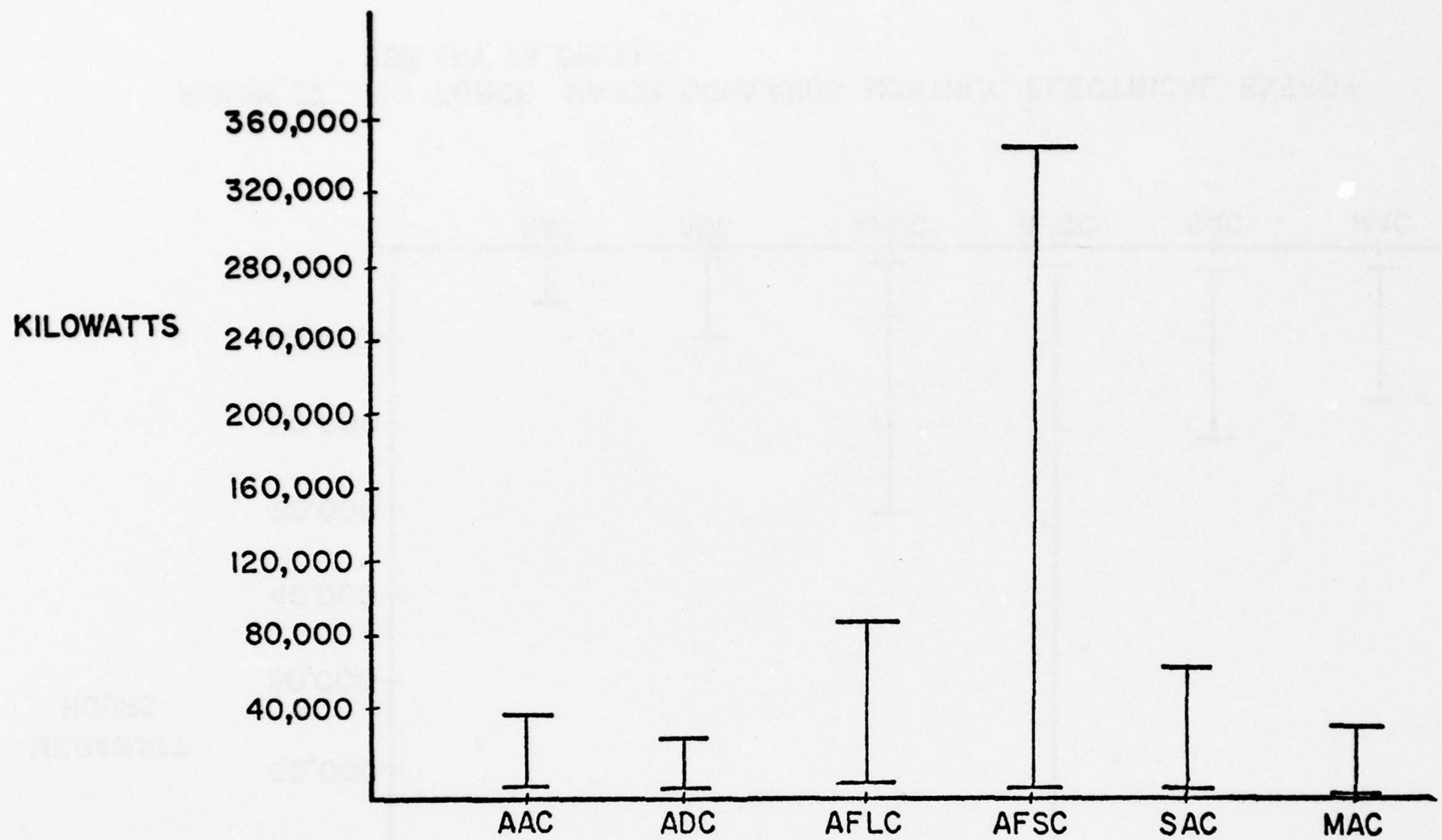


FIGURE III. AIR FORCE MAJOR COMMANDS MAXIMUM AVERAGE DEMAND RANGES (FY 75 ONLY)

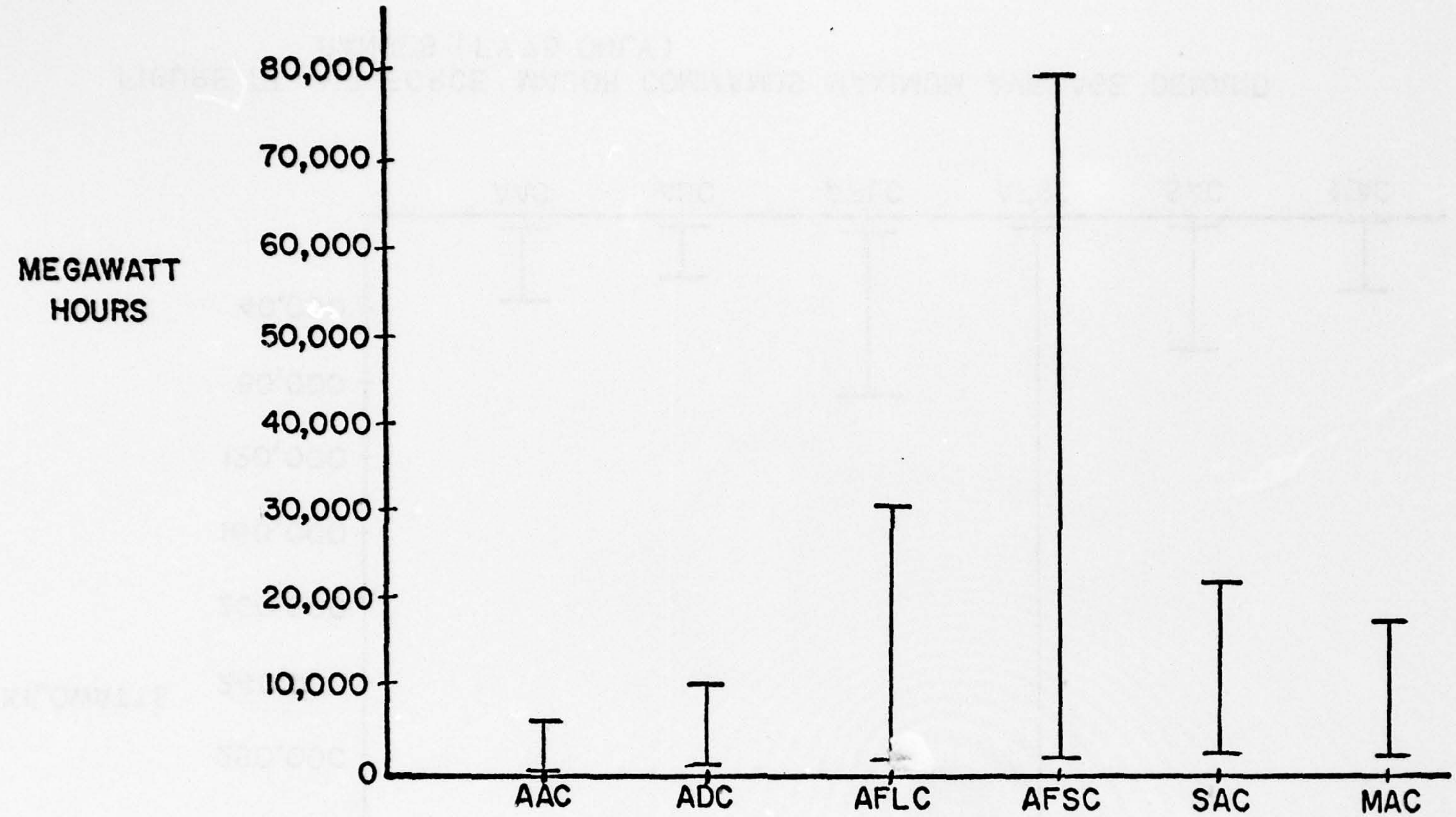


FIGURE IV. AIR FORCE MAJOR COMMANDS MONTHLY ELECTRICAL ENERGY USE (FY 75 ONLY)

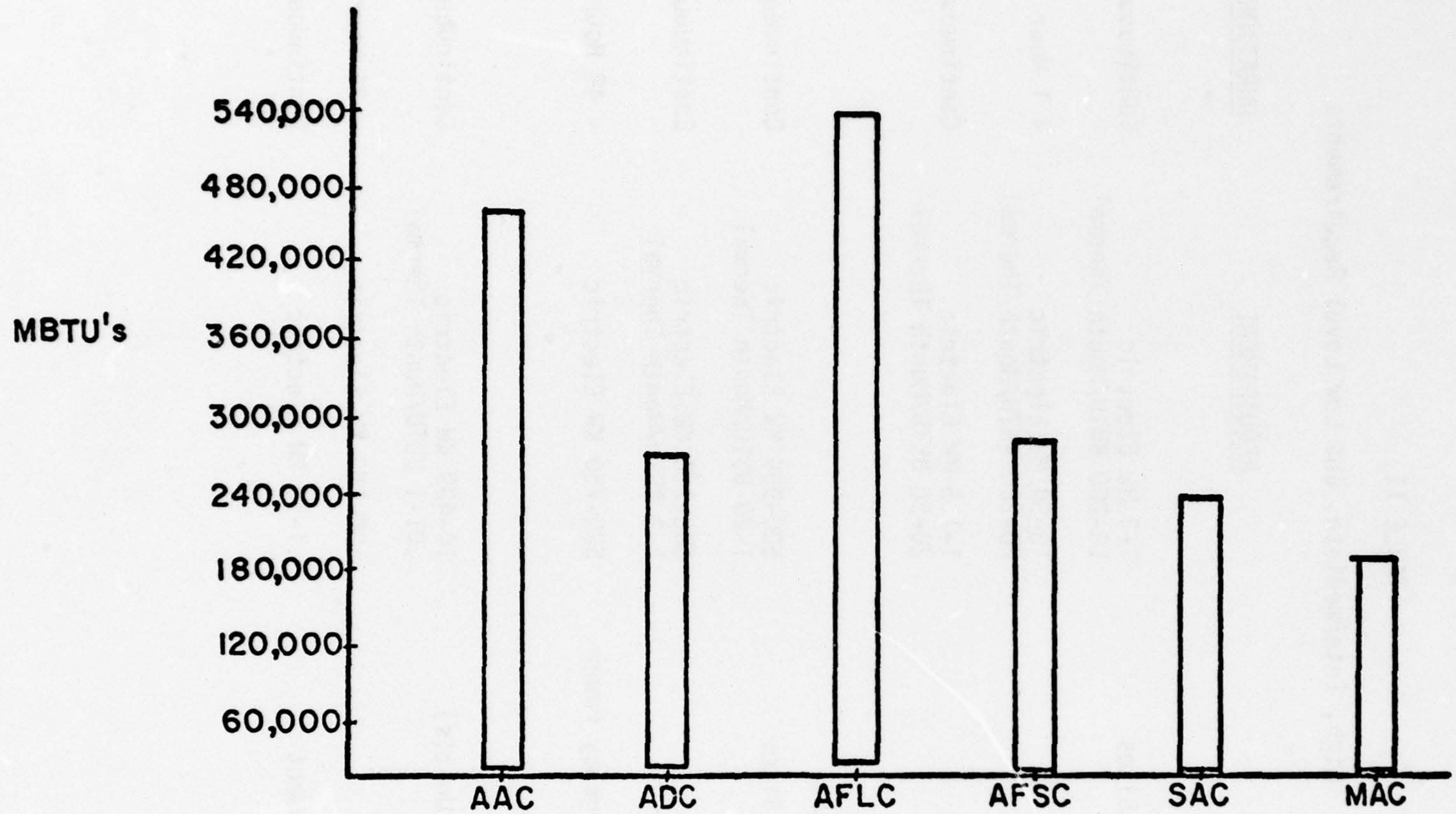


FIGURE V AIR FORCE MAJOR COMMANDS MONTHLY THERMAL ENERGY USE (FY 75 ONLY)

TABLE II

Examples: High, Intermediate, and Low Level Requirements

SYSTEM	REQUIREMENT	DURATION
HIGH LEVEL		
Residential Sites	1-3 Mw Electric 10-200 BBTU/Month Thermal	Continuous
Test Cells	10-50 MW Electric 20-200 BBTU/Month Thermal	< 1 Hour
Remote Sites	1-1.5 MW Electric 20-50 BBTU/Month Thermal	Continuous
INTERMEDIATE LEVEL		
Residential Sites	500-999 KW Electric 1-20 BBTU/Month Thermal	Continuous
Hospitals	500-750 KW Electric 1-3 BBTU/Month Thermal	Continuous
Standby/Emergency Power	500-750 KW Electric	< 48 Hours
LOW LEVEL		
Residential Unit(s)	10-499 KW Electric .01-1 BBTU/Month Thermal	Continuous
Test Cell	100-150 KW Electric	< 24 Hours
Remote Equipment	.1-10 KW Electric	Continuous

TABLE III

ELECTRICAL ENERGY LEVELS

Power Level	Continuous	8 Hours/Day	1 Hour/Day
1-10 KW (AC/DC)	X	X	X
25-50 KW (AC)	X	X	X
100-250 KW (AC)	X		
500-750 KW (AC)	X		
1-10 MW (AC)	X	X	X
25-50 MW (AC)	X		X

TABLE IV

THERMAL·ENERGY LEVELS

Steam			Water		
Pressure	Temperature	Flow Rate	Pressure	Temperature	Flow Rate
40 PSI	$270^{o}F$	20,000 lbs/hr	14.7 PSI	$140^{o}F$	20,000 lbs/hr
100 PSI	$330^{o}F$	20,000 lbs/hr	14.7 PSI	$180^{o}F$	20,000 lbs/hr
125 PSI	$345^{o}F$	20,000 lbs/hr	14.7 PSI	$200^{o}F$	20,000 lbs/hr
200 PSI	$389^{o}F$	20,000 lbs/hr	400 PSI	$400^{o}F$	20,000 lbs/hr
650 PSI	$500^{o}F$	20,000 lbs/hr			

SECTION III

Energy Conversion Systems

There are a number of energy conversion systems, presently available or in some stage of development, capable of satisfying USAF energy requirements. The main task is to select the optimal systems that will satisfy the requirements in the most economically, environmentally, and militarily advantageous manner. To do this, it is necessary to be able to examine and compare every energy source/conversion system with all others on equal terms. A large portion of the Terrestrial Energy Study was devoted to compiling an energy source/conversion system data base in order to accomplish this task.

Three basic energy sources were determined to be the most useful to the USAF; fossil, nuclear, and solar. The other energy sources (geothermal, gravitational, and refuse) would be useful in meeting some USAF requirements, but have a much lower overall applicability. Twenty-one types of energy conversion systems utilizing fossil, nuclear or solar sources were considered. These include nineteen types that utilize one of the three sources and two types that utilize electric power for recharging (energy storage systems). These systems are named in Table V. Each system is characterized in terms of a set of economic, physical and performance parameters that include acquisition cost, life cycle cost, size, system efficiency, and fuel use (Table VI). A total of eighteen such parameters were obtained for each system for each of the applicable energy levels from Table III. The levels and the systems are defined in terms of electric power level, voltage level, frequency, and duration of operation that correspond to general USAF terrestrial applications.

This data base is presented in two main reports, the Summary Data Display and the Energy Conversion Systems Handbook. The Summary Data Display is subdivided into 17 segments, one for each of the electrical power levels of Table III. Each segment presents charts which graphically display the values of the parameters for each type of energy conversion system. An example of these charts is shown in Figure VI. The Handbook is subdivided into 21 segments, one for each type of energy conversion system. Each segment presents tables of the values of the parameters for each electrical power level considered appropriate for that particular system. Examples of the tables are shown in Figure VIIa&b.

TABLE V

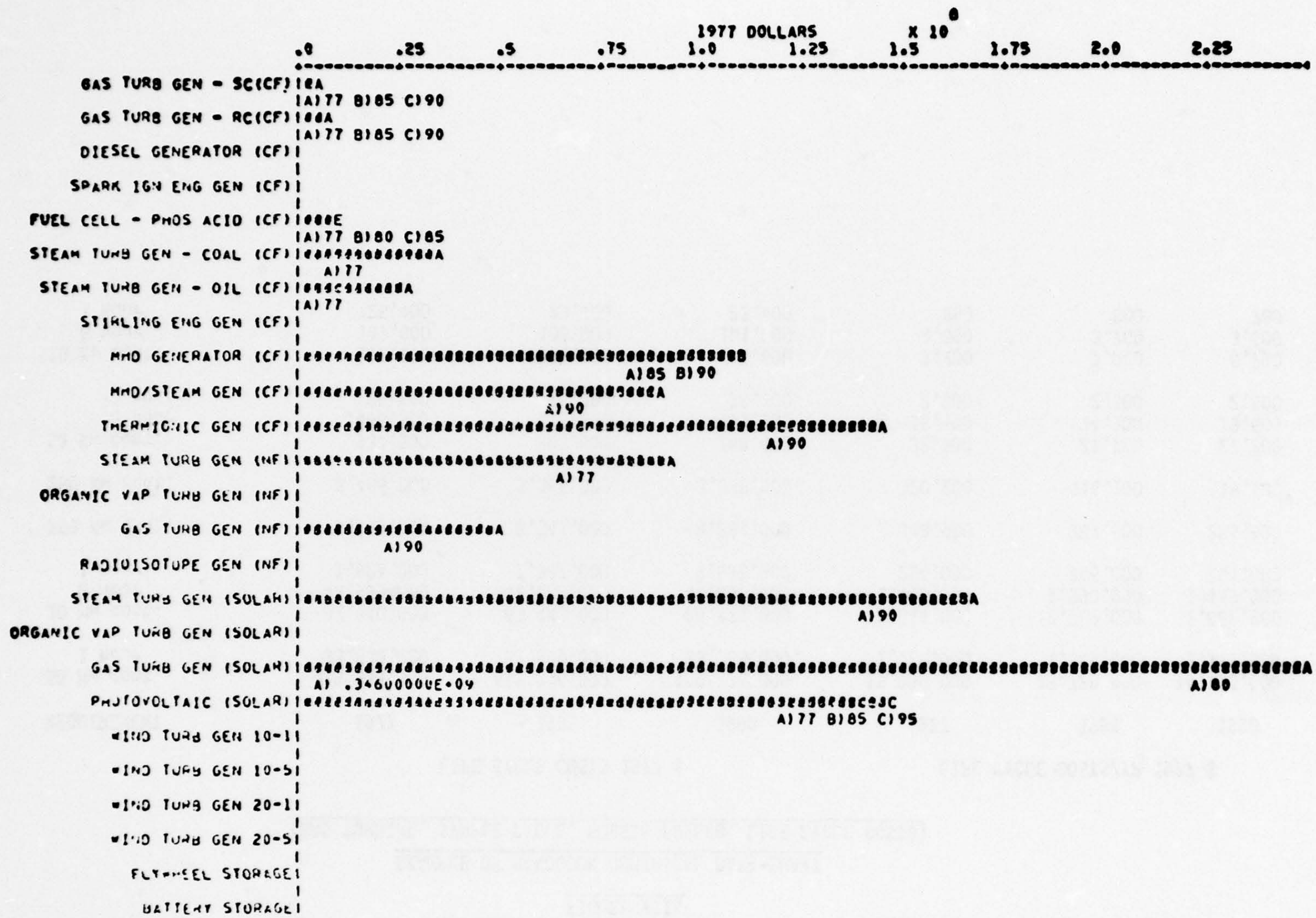
TYPES OF ENERGY CONVERSION SYSTEMS CONSIDERED
AND CORRESPONDING ELECTRICAL POWER LEVELS

ENERGY SOURCE	ENERGY CONVERSION SYSTEM	ELECTRICAL POWER LEVELS 50 MW	10 MW	750 KW	250 KW	50 KW	10 KW
1) Chemical	Gas Turbine Generator (simple cycle)	X	X	X	X	X	X
2) Chemical	Gas Turbine Generator (regenerative)	X	X				
3) Chemical	Diesel Engine Generator		X	X	X	X	X
4) Chemical	Spark Ignition Engine Generator			X	X	X	X
5) Chemical	Fuel Cell (phosphoric acid)	X	X	X	X	X	X
6) Chemical	Steam Turbine Generator (coal fired)	X	X	X			
7) Chemical	Steam Turbine Generator (oil/gas fired)	X	X				
8) Chemical	Stirling Engine Generator		X	X	X	X	X
9a) Chemical	MHD Generator	X	X				
9b) Chemical	MHD/Steam Generator	X					
10a) Chemical	Thermionic Generator			X	X	X	X
10b) Chemical	Thermionic/Steam Generator	X	X				
11) Nuclear	Steam Turbine Generator (PWR)	X					
12) Nuclear	Organic Vapor Turbine Generator			X	X	X	
13) Nuclear	Gas Turbine Generator (closed cycle)	X	X	X	X	X	
14) Radioisotope	Gas Turbine Generator (closed cycle)						X
15) Solar	Steam Turbine Generator	X	X				
16) Solar	Organic Vapor Turbine Generator			X	X	X	X
17) Solar	Gas Turbine Generator	X	X	X	X	X	X
18) Solar	Photovoltaic System	X	X	X	X	X	X
19) Wind	Wind Turbine Generator		X	X	X	X	X
20) External	Flywheel Storage	X	X			X	X
21) External	Battery Storage	X	X			X	X

TABLE VI

LIST OF PARAMETERS

1. Acquisition Cost (1977$)
2. Life Cycle Cost (1977$)
3. Volume/Size
4. Weight
5. Fuel (Type, Amount, Cost)
6. Environmental Constraints
7. Location Constraints
8. Operational Constraints
9. Lifetime
10. System Efficiency
11. Type of System
12. Start-up/Shut-Down Times
13. Growth Potential
14. Reliability
15. Maintenance and Operation
16. Other Energy Production
17. Availability of Building Materials
18. Stage of System Development



REQUIREMENT: 50 MW CONTINUOUS PARAMETER: 1 ACQUISITION COST

FIGURE VI EXAMPLE OF SUMMARY DATA DISPLAY CHART

FIGURE VIIa

EXAMPLE OF HANDBOOK NUMERICAL DATA CHART

(GAS TURBINE, SIMPLE CYCLE, FOSSIL FUELED, LIFE CYCLE COSTS)

	LIFE CYCLE COSTS 1977 $			LIFE CYCLE COSTS/YR 1977 $		
REQUIREMENT	1977	1985	1990	1977	1985	1990
50 Mw cont.	419,875,000	411,846,000	429,176,000	13,996,000	13,728,000	14,306,000
1 hour	33,838,000	32,699,000	33,358,000,	1,128,000	1,089,000	1,112,000
10 Mw cont.	87,340,000	83,443,000	86,471,000	2,911,000	2,788,000	2,882,000
8 hour	43,950,000	42,689,000	44,058,000	1,465,000	1,390,000	1,469,000
1 hour	7,621,000	7,387,000	7,525,000	254,000	246,000	251,000
750 Kw cont.	9,249,000	8,341,000	8,281,000	318,900	287,600	285,500
250 Kw cont.	3,486,000	3,366,000	3,338,000	120,200	116,100	115,100
50 Kw cont.	937,500	803,600	788,400	32,300	27,700	27,200
8 hour	465,500	412,600	393,500	16,100	14,200	13,600
1 hour	85,500	76,300	75,200	2,900	2,500	2,500
10 Kw cont.	228,500	202,900	195,600	7,900	7,000	6,700
8 hour	117,000	106,000	101,000	4,000	3,700	3,500
1 hour	25,400	23,900	23,400	850	800	780

SYSTEM	Thermal discharge (a)	Thermal discharge (b)	CO	HC	NO_x	SO_x	Noise	Particulates	Solid Waste	Chemical Waste	Radioactive Waste
GAS TURB GEN - SE (CF)	–	–	○	○	●	◓	◓	◓	–	–	–
GAS TURB GEN - RC (CF)	–	–	○	○	●	◓	◓	◓	–	–	–
DIESEL GENERATOR (CF)	–	–	○	○	◓	◓	◓	◓	–	–	–
SPARK IGN ENG GEN (CF)	–	–	○	○	◓	–	◓	–	–	–	–
FUEL CELL - PHOS ACID (CF)	–	–	–	–	–	–	◓	–	–	–	–
STEAM TURB GEN - COAL (CF)	–	●	○	○	◓	●	◓	●	●	○	–
STEAM TURB GEN - OIL (CF)	–	●	○	○	◓	●	◓	◓	●	○	–
STIRLING ENG GEN (CF)	–	–	○	○	◓	◓	◓	◓	–	–	–
MHD GENERATOR (CF)	–	–	○	○	●	◓	◓	●	●	–	–
MHD/STEAM GEN (CF)	–	●	○	○	●	◓	◓	●	●	–	–
THERMIONIC GEN (CF)	–	–	○	○	●	◓	○	◓	–	–	–
STEAM TURB GEN (NF)	–	●	–	–	–	–	◓	–	–	○	◓
ORGANIC VAP TURB GEN (NF)	–	●	–	–	–	–	◓	–	–	○	◓
GAS TURB GEN (NF)	–	●	–	–	–	–	◓	–	–	○	◓
RADIOISOTOPE GEN (NF)	–	–	–	–	–	–	–	–	–	–	–
STEAM TURB GEN (SOLAR)	–	●	–	–	–	–	◓	–	–	○	–
ORGANIC VAP TURB (SOLAR)	–	●	–	–	–	–	◓	–	–	○	–
GAS TURB GEN (SOLAR)	–	–	–	–	–	–	◓	–	–	–	–
PHOTOVOLTAIC (SOLAR)	–	–	–	–	–	–	–	–	–	–	–
WIND TURB GEN (ALL)	–	–	–	–	–	–	–	–	–	–	–
FLYWHEEL STORAGE	–	–	–	–	–	–	–	–	–	–	–
BATTERY STORAGE	–	–	–	–	–	–	–	–	–	–	–

FIGURE VIIb

EXAMPLE OF HANDBOOK QUALITATIVE DATA CHART
(ENVIRONMENTAL CONSTRAINTS)

SECTION IV

Technology Options

Although there are applications within the Air Force for each energy conversion system detailed in Section II, there are only a few systems which are generally useful in many applications. With the limited resources and stringent operational requirements of the Air Force, it is necessary to focus on the most generally useful technologies to minimize the inherent logistics and training burden. To accomplish this, the energy conversion systems were evaluated with respect to only four specific parameters. These parameters are life cycle cost, reliability, availability and operational constraints. Further refinement of the results can and should be accomplished; however, they are sufficient to indicate the potential of each technology for Air Force use.

Some of the technologies best suited to satisfying general Air Force requirements and their use potential are outlined in Tables VII and VIII and detailed below.

Fuel Cells

Fuel cells can be utilized in the near-term by the Air Force for ground transportation, mobile power generation systems, stationary power generation systems and as emergency/backup power systems. The potential for fuel cell use in each of these categories is as follows:

a. Ground transportation - Five thousand 30-300 KW Units
b. Mobile power systems - Five thousand 40-750 KW Units
c. Stationary power systems - Five thousand 250-1000 KW Units
d. Emergency/backup power systems - Five thousand 10-100 KW Units

Stirling Engines

Stirling engines can be utilized in the mid and far-term by the Air Force for ground transportation mobile power generation systems, stationary power generation systems and emergency/backup power systems. The potential for Stirling engine use in each of these categories is as follows:

a. Ground transportation - Thirty 500 KW Units
b. Mobile power systems - Five thousand 40-750 KW Units
c. Stationary power systems - Three thousand 250-750 KW Units
d. Emergency/backup power systems - Five thousand 10-100 KW Units

Improved Diesel Engines

Improved diesel engines can and will be utilized in the near-term as direct replacements for existing diesels. At the present time, diesels are used for some ground transportation, mobile and stationary power systems, and emergency/backup power systems. The potential for use within the Air Force in each category is as follows:

TABLE VII

STUDY ELECTRICAL RESULTS

SYSTEM	CONTINUOUS						8 HOURS			1 HOUR			
	10KW	50KW	250KW	750KW	10MW	50MW	10KW	50KW	10MW	10KW	50KW	10MW	50MW
Diesels	X	X								X	X		
Fuel Cells	0	0	0	0	X		0	0	0	0	0	0	0
Stirling Engines	0	0	0	X			0	0		0	0	0	
Solar Turbine			X	X	X				X				
Gas Turbine			X	0	0							X	X
Wind Turbine				X	0				0	0		0	
Nuclear Steam Turbine					0								
Photovoltaics	X	X	X	X									
MHD					0								0
Coal Fired Steam Turbine				0	0								0

0 - Most Promising
X - Promising

TABLE VIII

THERMAL RESULTS
(IN PRIORITY ORDER)

LEVEL		ENERGY SYSTEMS
STEAM (CONTINUOUS)		
	HIGH PRESSURE	GAS FIRED BOILER
		OIL FIRED BOILER
		COAL FIRED BOILER
	LOW PRESSURE	GAS FIRED BOILER
		OIL FIRED BOILER
		COAL FIRED BOILER
		SOLAR FIRED BOILER
WATER (CONTINUOUS)		
	HIGH TEMPERATURE	GAS FIRED BOILER
		OIL FIRED BOILER
		COAL FIRED BOILER
	LOW TEMPERATURE	GAS FIRED BOILER
		OIL FIRED BOILER
		COAL FIRED BOILER
		SOLAR FIRED BOILER

a. Ground transportation - One thousand 250-750 KW Units
b. Mobile power systems - Ten thousand 1-750 KW Units
c. Stationary power systems - Five thousand 250-1000 KW Units
d. Emergency/backup power systems - Five thousand 10-100 KW Units

Coal Gasification

Coal gasification, especially combined cycle type plants, can be utilized in the near and mid-term as fuel supply units. The categories of use would be base level selective energy plants. The potential for use within the Air Force is on the order of fifty 10,000 MCF/DAY, 1-30 MW plants.

Solar Technologies

The solar technologies (solar thermal, photovoltaics and wind) can be used in the near, mid and far-term in a fuel-saving mode. Their best use is to reduce the logistics and maintenance burdens associated with remote power generation. The near-term potential for solar technology use within the Air Force are as follows:

a. Photovoltaics - 5-10 MWe of 500W - 10 KW Systems
b. Solar thermal - 10 MWe/10MW_{th} distributed receiver high temperature systems, 10-15 sites
c. Solar thermal - Low temperature (500^{o}F) systems for retrofit existing and new building hot water systems
d. Wind - 1-50 MWe systems, specific sites

Integrated Thermal/Electrical Generation

Integrated thermal/electrical generation (cogeneration) systems are the most efficient users of energy. All the technologies mentioned above could be used as subsystems in a cogeneration system and achieve high energy efficiencies. The categories of use and potential for use of cogeneration systems would be as detailed under each separate technology.

Some of the potential uses detailed above are mutually exclusive. Each of the technologies can be used for the same task, with the one chosen depending on operational constraints. For example, a photovoltaic or a wind system could be used at the same remote site, depending upon first cost and location. At the present time, more detailed assessments of the most promising technologies are being done. These assessments, coupled with development programs aimed at optimizing the technologies for military use will define the total Air Force use potential of each technology.

SECTION V

Conclusions and Recommendations

The emerging technologies, and improvements on existing technologies, can have a dramatic impact upon total Air Force energy use and force readiness. The total potential impact on energy use, as seen by this office, is shown in Figure VIII. The potential for improving force readiness is less quantifiable, but nonetheless significant. Figure VIII is based upon the Air Force following a comprehensive plan of gradual integration of new technologies, systems and designs. Air Force terrestrial use of energy extends over a large, extremely diversified, interrelated area that includes thousands of ground vehicles; remote sites; combat and maintenance operations; residential, commercial and industrial facilities; testing sites and related equipment; and operations in every type of climate. To successfully reduce the energy use in one sector without reducing force readiness or increasing energy use in another sector requires an overall plan. Attempted piecemeal integration of new equipment can, and probably will, increase rather than decrease the drain on our resources.

The main conclusions reached in this study are:

a. that the USAF can benefit significantly, both from economic savings and increases in force readiness, by utilizing new and developing technology in the terrestrial area.

b. that certain military related requirements are not being incorporated into the new technology (Table IX).

The main recommendation from this study is that the Air Force adopt a realistic, comprehensive energy plan and assign to it the resources and management support necessary to fully implement it. If this is done, the USAF can benefit significantly, both in economic savings and increases in force readiness. The economic savings will accrue from the reduction in energy use and is, in itself, great incentive to adopt an energy plan. However, an added benefit to adopting and implementing an energy plan will be an increase in force readiness. This is expected to be accomplished by the introduction of advanced technology into the support functions. This technology will enable the support functions to operate at maximum efficiency and with minimum dependency on outside energy supplies.

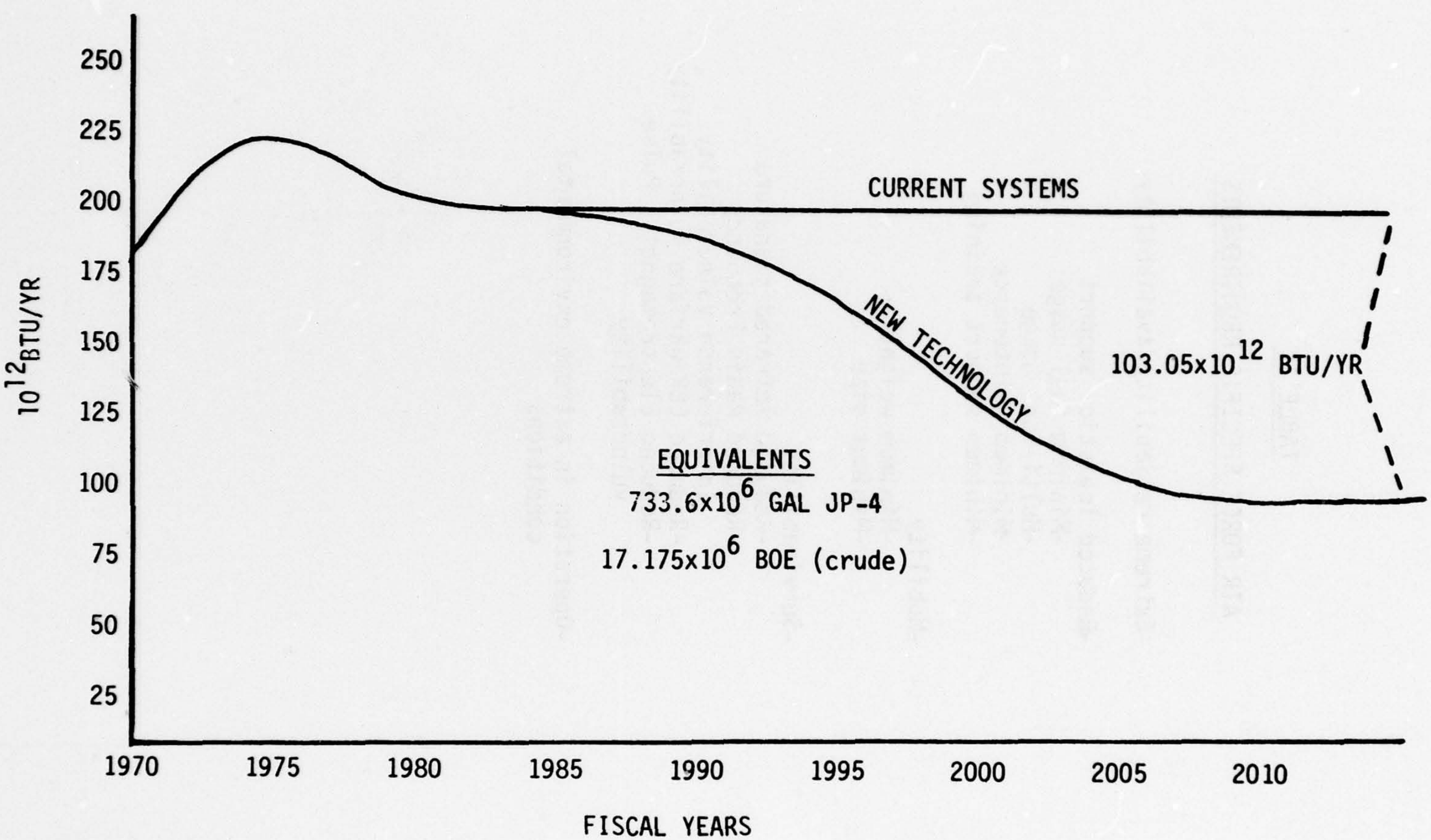


FIGURE VIII. POTENTIAL IMPACT ON USAF TERRESTRIAL ENERGY USE

TABLE IX

AIR FORCE SPECIFIC REQUIREMENTS

-Extreme reliability/availability

-Reduced logistics support
- -Minimum fuel usage
- -Multi-fuel usage
- -Minimum maintenance
- -Minimum support training

-Mobility
- -Minimum weight
- -Minimum size

-Survivability
- -Reduced Infrared signature
- -Reduced Radio Frequency Interference vulnerability
- -Reduced CBR warfare vulnerability
- -Reduced Electromagnetic Pulse vulnerability

-Operation in extreme environmental conditions

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